EVALUATION AND ESTIMATION OF REFERENCE POINTS FOR THE CRAB STOCKS (*Callinectes spp.*) FROM THE GULF OF CALIFORNIA AND WEST COAST OF BAJA CALIFORNIA SUR, MEXICO

AUTHORS

Alejandro Balmori-Ramirez (Instituto Nacional de Pesca y Acuacultura)

Gabriel Iván Rivera Parra (Instituto Nacional de Pesca y Acuacultura)

Rufino Morales Azpeitia (Centro de Investigaciones Biológicas del Noroeste)

Andrés Antonio Seefoo-Ramos (Independent consultant)

February 2021

SUMMARY

In the Mexican Pacific, particularly the northwest region, the crab fishery has gained importance among the nearshore fisheries, occupying the second place in production volumes, after the shrimp fishery. Fishery management generally involves decision-making based on the evaluation of the population size (biomass) and population dynamics, in order to maintain desired levels of exploitable biomass over time; in small-scale fisheries, the information required to develop such estimates is often more difficult to obtain. Biological reference points to inform management are usually derived from models that are difficult to understand and often require large amounts of input data. The Catch-Maximum Sustainable Yield (C-MSY) method allows estimation of reference points that can be used for management of a fishery, such as catch at maximum sustainable yield (MSY), the biomass associated with MSY (B_{MSY}) and the fishing mortality associated with maximum sustainable yield (F_{MSY}), using limited data. A 1980-2018 official landings series was used, to determine the level of exploitation of the warrior (*Callinectes bellicosus*) and cuata (*C. arcuatus*) swimcrab resources for the Mexican Pacific northwest region (Gulf of California and west coast of the Baja California). For the Gulf of California, the warrior swimcrab the MSY and B_{MSY} found by the C-MSY method were 19,272 t and 32,356 t, respectively. For the Gulf of California cuata swimcrab the values of MSY and B_{MSY} were estimated at 4,479 t and 7,520 t, respectively, and, for the west coast of the Baja California warrior swimcrab, the values of MSY and B_{MSY} were estimated at 736 t and 1,236 t, respectively. The F_{MSY} value was 0.596 for the three stocks. The results indicate that the Gulf of California crab fishery is at maximum exploitation levels and is experiencing overfishing, while for the crab stock on the west coast of the Baja California peninsula, the estimated biomass for the last year of the series is below the B_{MSY}, potentially approaching an overfished state, and with the fishing mortality above the F_{MSY}, thus experiencing overfishing. To maintain the Gulf of California swimcrab species biomass at sustainable levels its recommended to establish and enforce annual Total Allowable Catches (TAC) around 17,345 t (0.9 MSY) for warrior crab fishery and 4,031 t (0.9 MSY) for cuata crab fishery or for both species fishing mortality limits at 0.9 F_{MSY}. For the Baja California Sur warrior crab fishery, it is recommended, to establish and enforce annual TAC equal or below of 589 t (0.8 MSY) or fishing mortality limits at 0.9 F_{MSY}.

2. Objectives

- To determine the stock status of the swimcrab stocks in the coast of the Gulf of California and the west coast of Baja California.
- To estimate appropriate candidate reference points for these different stocks of swimcrabs.

3. Study Area

The study area includes the coast of the Gulf of California and the west coast of the Baja California Sur state (Figures 1 and 2).

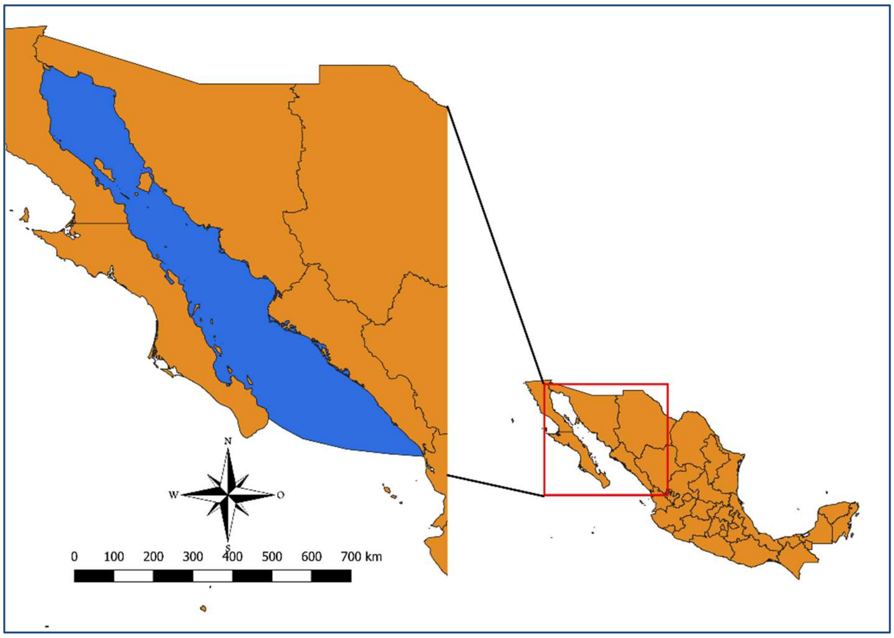

Figure 1. Study area for *C. bellicosus* and *C. arcuatus* in the Gulf of California

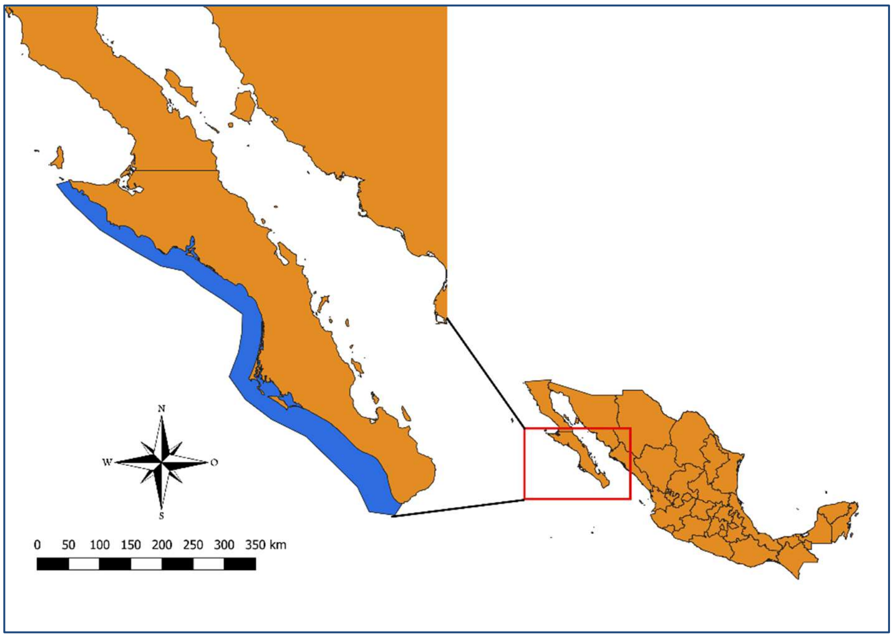

Figure 2. Study area for *C. bellicosus* on the west coast of Baja California Sur.

5. Methods

One part of the methodology consisted of the analysis of the historical official landings records (t/year) and another of the application of the Catch-MSY (C-MSY) method described by Froese *et al.* 2017.

Catch Trends by Stock

The information on the live weight catches was taken from official crab catch records from the Statistical Fishing Yearbooks for the 1980 to 2018[1] period. In this base, all the species of the *Callinectes* family that bear the common name crab were grouped and later they were disaggregated by species, according to the participation percentages described in the National Fisheries Chart 2018.

Stock Assessment, Limit Reference Point (LRP), Target Reference Point (TRP) Fishing Mortality (F)-based Reference Points

For the purposes of this study the warrior swimcrab fishery in the Gulf of California was considered to fish on a single stock (WC_GC), according to Pfeiler *et al*. 2005. The warrior swimcrab from the West coast of the Baja California Sur, was also considered a separate, single stock (WC_BC). Similarly, the cuata swimcrab from the Gulf of California was evaluated as a single stock (CC_GC).

The C-MSY method described by Froese *et al*. 2017 was applied. This, through the Monte Carlo method, estimates the reference points of the fishery (MSY, F_{MSY}, B_{MSY}), as well as the relative size of the population (B/k) and the exploitation rate (F_t/F_{MSY}). This method requires the estimation of the stock biomass at the beginning and end of the time series, expressed as intervals of proportion of virgin biomass (k or carrying capacity); to define these intervals of the state of the stock (B/k), the authors of the method propose a range of values both initial (λ_{i1}, λ_{i2}) and final (λ_{f1}, λ_{f2}), based on the proportion of catches at the beginning and end of the time series, relative to the maximum recorded catch. This method also requires the general background of resilience and productivity (r) to be known. The same authors propose values of r based on the level of resilience of the species, in case there is no previous stock-based value of resilience.

Another important feature of the C-MSY is that it differs from an earlier version of the Catch-MSY method (Martell and Froese, 2012) by searching for the most probable r not in the center but rather in the tip of the triangle. This is based on the underlying principle that defines *r* as the maximum rate of increase for the examined population, which should be founded among the highest viable *r*-values, i.e. *r* is defined as maximum net productivity.

[1] https://www.gob.mx/conapesca/documentos/anuario-estadistico-de-acuacultura-y-pesca

Part of the C-MSY package is a spatial implementation of the Bayesian state of Schaefer's surplus production model (BSM). The main advantage of BSM compared to other surplus production model implementations is the focus on informative background and data acceptance brief and incomplete (fragmented) abundances (Froese *et al.* 2017), the initial biomass was calculated as:

$$B_0 = \lambda_{i1} k * \exp(\upsilon t) \qquad \text{Eqn 1}$$

and the biomass of the following years as:

$$B_{t+1} = \left[B_t + rB_t\left(1 - \frac{B_t}{k}\right) - C_t\right] * \exp(\upsilon t) \qquad \text{Eqn 2}$$

Where:

B_t = Biomass at time t

B_{t+1} = Biomass one time-step after t

C_t = Capture at time t, and

exp (vt) = process error. If the process error is equal to 0, it is considered a deterministic model and if it is equal to 1, it is considered an observation error (uncertainty).

To account for reduced recruitment at severely depleted stock sizes (depensation), such as predicted by all common stock–recruitment functions (Beverton and Holt 1957; Ricker 1975; Barrowman and Myers 2000), this method incorporates a linear decline of surplus production (a function of recruitment, somatic growth and natural mortality (Schnute and Richards 2002)), when biomass falls below ¼ k (Equation 3).

$$B_{t+1} = \left[B_t + 4\frac{B_t}{k}r\left(1 - \frac{B_t}{k}\right) - C_t\right] * \exp(\upsilon t) \qquad \text{Eqn 3}$$

It was assumed that, at the beginning of the time-series, the biomass of the swimcrab stocks for the three fisheries varied between 50% and 90% (B/k = λ_{i1}, λ_{i2}) of their respective carrying capacities (k), and in the last year, between 30% and 70% (B/k = λ_{f1}, λ_{f2}) for the warrior (WC_GC) and cuata (CC_GC) swimcrab stocks in the Gulf of California and between 30% and 40% for the west coast of Baja California stock (WC_BC). The biological plausible range for r for species with high resilience (0.6 < r < 1.5 Froese *et al.* 2017) was considered appropriate for all the crab stocks.

To note a key uncertainty, there are many catches that are not correctly recorded, mainly when it comes to small-scale fisheries. The lack and low precision of information is usually considerably greater for the small-scale fleet than for the industrial fleets (Arreguín-Sánchez & Arcos-Huitrón, 2006), as some crab is not sold and therefore goes unrecorded in the official capture statistics. To address this, the input values of CV and process error used in the method were 0.2 (20%) and 0.1, respectively. In all cases, 30,000 MCMC iterations were performed.

The parameters estimated by C-MSY and BSM relate to standard fisheries reference points, such that

$$MSY = r\ k/4, \quad \text{Eqn 4}$$

$$B_{MSY} = 0.5\ k, \quad \text{Eqn 5}$$

$$F_{MSY} = 0.5\ r, \quad \text{Eqn 6}$$

If the reduction in recruitment at very slow stock sizes (B / k < 0.25), instead

$$F_{MSY} = 0.5\ r\ 4\ B/k. \quad \text{Eqn 7}$$

The version of the R script of the C-MSY method used here (MSY_O_7q.R), is newer than that used in Martell and Froese (2012).

Equilibrium Curve

By means of the equilibrium curve graph (Equation3), the relation of the relative biomass of the population (B_t/k) vs the relative catch (C_t/MSY) is shown, and allows visualizing the behavior of the respective rates with respect to the carrying capacity (k) or virgin biomass.

Crab Production Rates

According to the Schaefer model, the net surplus production (SP) in a period of time t of a population subject to fishing is defined as (Anderson and Seijo, 2010, Seijo *et al.* 1997):

$$SPt = rBt\left(1 - \frac{Bt}{k}\right) \quad \text{Eqn 8}$$

Where *r* is the intrinsic rate of population growth and k is the carrying capacity of the population.

In the case of exploited stocks, the annual biomass (B_t) can be estimated by relating it to the instantaneous rate of surplus production (ρ_t) (Jacobson *et al.* 2001):

$$B_{t+1} = B_t e^{\rho_t - F_t} \quad \text{Eqn 9}$$

Where F_t is the instantaneous fishing mortality rate defined as the ratio between the accumulated catch in a fishing period and the average biomass in the same period, or $F_t = C_t/B_t$ (Jul-Larsen *et al.* 2003). So,

$$\rho_t = \ln\left(\frac{B_{t+1}}{B_t}\right) + F_t \quad \text{Eqn 10}$$

Furthermore, ρ_t is related to the annualized surplus production of the stock (SP_t) as follows (Jacobson *et al.* 2001):

$$\rho_t = \ln\left(\frac{SP_t + B_t}{B_t}\right) \quad \text{Eqn 11}$$

Units are by time and measure the instantaneous population growth rate resultant from individual growth, recruitment, fishing mortality, and natural mortality. This standardized formulation makes it possible to compare the productivity of different stocks or to relate it to either environmental or biological indices.

A Kobe plot was constructed (Aires-da-Silva and Maunder, 2011, Schirripa, 2016), which allows a plot of assessment from the perspective of the exploitation rate (F_t/F_{MSY}) and the relative biomass (B_t/B_{MSY}), and summarizes stock status by plotting points by colored quadrant: green quadrant (not overfished, no overfishing), yellow and orange quadrant (overfished or overfishing), and the red quadrant (overfished and overfishing). It can also be used to guide the choice of reference points for use as part of a standard management strategy (Laurence *et al* 2014).

Candidate Reference Points

There is no universally recognized best method for setting fisheries targets and limits, however, the establishment of reference points is intended to guide a possible standard management strategy that results in long-term sustainability of the target fishery, benefitting both the fishers and the target fish population. The population biomass should be managed to fluctuate around a target reference point (TRP) compatible with MSY (MFNZ, 2008), but not generally be allowed fall below the limit reference point (LRP).

As is traditional, we suggest that the biomass TRP is established as equal to the B_{MSY}. A threshold of around 0.5 B_{MSY} has been widely adopted as a biomass LRP to prevent recruitment overfishing (Froese *et al*. 2017; Haddon *et al* 2012; Carruthers *et al* 2014; Froese *et al* 2015). Additionally, we recommend a fishing mortality limit reference point at the value of F_{MSY} produced by the model, such that any value above this is considered overfishing. In summary, the advised candidate reference points are:

$$TRP_{BMSY} = B_{MSY} \quad \text{Eqn 12}$$

$$LRP_{BMSY} = 0.5\ B_{MSY} \quad \text{Eqn 13}$$

$$LRP_{FMSY} = F_{MSY} \quad \text{Eqn 14}$$

With the information generated by the C-MSY method, candidate values for appropriate TRP and LRP were established. Kobe plots were constructed to show the evolution of the stocks relative to the candidate target and limit reference points and provide information on the stock status and exploitation rate. Likewise, it allowed evaluating the uncertainty of the current status by establishing the variation of these results.

To test the effect of the establishment of possible standard management strategies of limiting catch or fishing mortality, and evaluate their effect on the trend of the stock biomass, the Schaeffer model (constant captures) was used. For catch limits, the values tested were MSY, the lower confidence interval of MSY, as well as several values in between. For fishing mortality limits, the values tested were F_{MSY} as well as 0.9, 0.8 and 0.7 F_{MSY}.

6. Conclusions

The C-MSY method determines the most viable pair of *r*-k that corresponds to the estimated biomass trajectory that is compatible with the observed catches and, from there, estimates the relative biomass ranges for the beginning and end of the respective time series and the respective reference points. In general, the confidence intervals indicate that the possible true value is within that range. For the warrior and cuata swimcrab fisheries of the Gulf of California and the west coast of Baja California Sur, the confidence intervals were wide for all the estimated parameters. With more robust fishery and fishery-independent data, different models could be applied, which could reduce the uncertainties inherent in this approach. For a data limited fishery, such as this one, the C-MSY method provides a valuable scientific perspective from which to develop scientific advice to managers. This advice can provide the basis on which to take interim fishery management decisions such as choices of harvest strategies and harvest control rules, to be refined when more robust data and associated advice become available.

The C-MSY model yielded a value of *r,* which indicates the maximum net productivity equal to 1.190 with confidence intervals of 0.957 to 1.480, that could be explained by a wide range of large stock sizes and low productivity (high resilience) or by a narrow range of small stock sizes and high productivity (Froese *et al.* 2017). The estimated value of *r* is within the high resilience range proposed by Froese *et al.* 2017.

The highest k values were for the WC_GC and the CC_GC stocks with a relative biomass in the last year of 0.567 k and 0.536 k, respectively. The WC_BC stock presented a relative biomass in the last year of 0.350 k. Exploitation rates of the three stocks were above the F_{MSY} (0.596), with values in the last year of 1.17 for the WC_GC, 1.11 for the CC_GC and 1.16 for the WC_BC.

The equilibrium curve shows stocks with high resilience and with a decreasing biomass as catches increase, including the phases of decrease, increase and equilibrium, as shown by the position of the points below, above and near the equilibrium curve (Figure 8).

The catch at maximum sustainable yield (MSY) estimated by the C-MSY method was 19,272 t for the WC_GC, 4,479 t for the CC_GC and 736 t for the WC_BC. For all stocks evaluated the catches of the last four years were greater than MSY, except for the WC_BC stock, for which the catch of the final year (2018) declined below the MSY.

The Gulf of California and west coast Baja California stocks of warrior and cuata swimcrabs evaluated in this research showed, during the last five years of the analyzed period, an average catch higher than the overall time-series average and exceeding the estimated MSY. This may have played a large role in the commensurate decreases in the population biomass of stocks, which have declined to levels approaching the candidate TRP_{BMSY} for the Gulf of California stocks, and below the candidate TRP_{BMSY} and nearing the candidate LRP_{BMSY} for the western Baja California stock.

For the WC_BC stock, an increase in fishing pressure or a combination of fishing and poor recruitment could have generated the observed decrease in biomass. The relative biomass in the last year analyzed was close to the $B/K < 0.25$ which indicates that the stock is, or is likely to be in the immediate future, experiencing stock-size related reduced recruitment. In addition, changes in the marine environment, such as El Niño, La Niña, and climate change, can play important roles in the recruitment success of these species.

The exploitation rates from 2010 showed a constant increase, and in the last year of the period, the fishing mortality was above F_{MSY}, defined here as the candidate limit reference point for fishing mortality, or LRP_{FMSY}; for the particular case of the WC_BC, the fishing mortality of the last four years exceeded the LRP_{FMSY}, indicating that fishing mortality needs to be reduced in this fishery.

The estimated biomass, for the cases of the WC_GC and CC_GC, is found throughout the recorded period above the B_{MSY} (defined here as the candidate target reference point for biomass, TRP_{BMSY}), though decreasing in recent years, while the biomass of the stock of WC_BC, in the last years of the analyzed period, is below the TRP_{BMSY}. The fact that the catches have exceeded the MSY in recent years indicates that the applied fishing effort was using the available biomass, causing it to decrease. None of the stocks have yet decreased below the candidate limit reference point for biomass (LRP_{BMSY}) or $0.5B_{MSY}$.

Jacobson *et al*. (2001) mentions that, for stocks with long time-series, biomass decreases are pronounced when the captures exceed the surplus production for a 5-year period or more (Figure 10). Surplus production was exceeded for each of the three stocks considered here, but only at the end of the time series, particularly for the WC_BC stock that shows a decrease in biomass, catches and surplus production.

The Kobe plots place the WC_GC and CC_GC stocks in the last year in an overfishing zone (orange color). The uncertainty indicators indicate that in the case of the WC_GC there is 67.7% probability that the status is in the orange quadrant, a 23.5% probability of it being located in the green quadrant (an area of greater sustainability) and 8.3% probability of it being located in the red quadrant (an overfished stock also experiencing overfishing). For the CC_GC the uncertainty indicators show that there is a 40.2% probability that the status is in the orange quadrant, with a 31% probability of it being located in the green quadrant, and a 22.3% probability of it being located in the red quadrant.

For the WC_BC, the Kobe plot places this stock in the overfished and experiencing overfishing zone in the last year, and the probability indicators show that there is 78% probability to remain the same and 22% to be located in the yellow quadrant.

It is of note that, for all three fisheries, stock status remained in good condition for many years but rapidly changed over the last four years to move into less favorable status. This is important from a management perspective as it demonstrates the speed needed by managers to respond to changes in the fishery and stock in order to keep the stock status in good condition. The number of boats in the Gulf of California participating in the swimcrab fishery increased by 42% in the 2011-2017 period and with exploitation rates in recent years above the LRP_{FMSY}. For the WC_BC stock, it is not clear if the status change in this short period of time is solely due the fishing effort increasing or a combination of increased fishing effort and reduced recruitment, a situation that should be further explored.

Projecting stock status forward over the next five years allowed testing of catch limits and fishing mortality limits as alternative management strategies. In order for the warrior and cuata swimcrab stocks of the Gulf of California to be in a status of good health with no overexploitation by 2025 would require a catch level less than or equal to 0.9 MSY. For the warrior swimcrab stock off the coast of Baja California Sur to be in a status of good health with no overexploitation by 2025 would require a catch level less than or equal to 0.8 MSY. This strategy would allow biomass to reach levels higher than TRP_{BMSY} and the fishing mortality to decreases to values below the F_{MSY}.

Considering the limitation of fishing mortality as a second strategy, all tested values of F equal to or less than F_{MSY} allowed biomass to increase to levels at or above B_{MSY} by 2025.

Based on the foregoing, we consider that the warrior and cuata crab stocks in the Gulf of California are not overfished, with biomass above the candidate TRP_{BMSY}, but are experiencing overfishing with fishing mortality values above the candidate limit reference point associated with F (F_{MSY}). The warrior crab fishery off the west coast of Baja California Sur is not overfished, though the biomass is between the candidate TRP_{BMSY} and LRP_{BMSY}, but it is experiencing overfishing with fishing mortality values above the candidate limit reference point associated with F (F_{MSY}).

7. Recommendations

- Fishery scientists and managers of the Gulf of California and Baja California Sur swimcrab fisheries should formally adopt the C-MSY methodology described here to enable on-going evaluation of stock status and provision of scientific advice to managers.
- Managers of the Gulf of California and Baja California Sur swimcrab fisheries should formally adopt the candidate reference points (at least as interim RPs) and use these in managing the fisheries.
- To maintain the biomass of each stock of the Gulf of California swimcrab at sustainable levels (i.e. around B_{MSY}), its recommended to establish and enforce annual Total Allowable Catches (TACs) of 17,345 t for WC_GC and 4,041 t for CC_GC fisheries, (around 0.9 MSY) or fishing mortality limits at or below 0.9 F_{MSY}.
- Based on this analysis, the Baja California Sur warrior swimcrab is experiencing overexploitation and is nearing an overfished state. It is therefore recommended to establish a TAC that will return the stock to B_{MSY} is a short period. This analysis shows that 588 t (0.8 MSY) would do this by 2025.
- To improve the swimcrab stock assessment, it is recommended to establish a comprehensive biological monitoring program, including catch, landings, size frequency, weight-at-size, and sex data, among others, for each species and stock.
- It is recommended to establish a periodic swimcrab stock assessment program to routinely evaluate the fishery performance and management outcomes for each stock.
- In order to ensure scientific advice from the stock assessment program is appropriately developed and used to inform management, it is also recommended to establish a clear advisory and decision-making process to manage the fishery. This process would enable management based on the appropriate use of TACs, effort limitation, closed areas, closed periods, minimum landing sizes and using the accepted and periodically updated limit and target reference points. This

process should be open, transparent and inclusive, with some level of peer-review of the science, and with full and timely publication of assessments and management decisions.